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Efficiency of Electrical Heating Apparatus

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EFFICIENCY OF ELECTRICAL HEATING APPARATUS

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

HOWARD DIXON BRALEY

ENTITLED EFFICIENCY OF ELECTRICAL HEATING APPARATUS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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* I N D E X *

Page.

--Introduction--

The investigation of efficiencies of electrical heating apparatus has been very limited, and it is the object of this thesis to set forth some theories upon the subject and to give the results of tests made, with a discussion of them. While true that there has been some work done along this line the methods employed were so variegated and the results so inconsistent that they are of very little practical use.

The writer has attemped to devise what shall be a standard method of testing electric flat irons. Flat irons are chosen as the subject of the investigation since they are typical of all electrical heating appliances in which heat is transmitted from one body to another by conduction, and the results obtained from them may be applied to other similar heating units. It is desirable to obtain the efficiency upon the basis of input to the output. Or, in other words, the ratio of electrical input (heat equivalent) to output from the bottom of the iron (heat equivalent). The direct value of these tests lies in the determination of the economy with which the irons may be operated, and hence influences their introduction into the household with the direct result of increasing the day load of the central station, or increase of the load factor. It is evident that if the operation of such units proves satisfactory and economical, that the purchase of all similarily operated utensils will be correspondingly increased.

In making these tests it was decided to use several makes of irons so that the results might be typical of all apparatus upon the market rather than to recommend one more than the other, and furthermore to point out the points in design that are conducive

to the best results.

Several manufacturers kindly sent samples of their product upon our request for them to co-operate with us in securing results. Three different kinds of irons suitable for either A.C. or D.C., were tested, and one make designed for A.C. alone.

A copper calorimeter containing water was the apparatus used. This calorimeter affords a means of getting into the water all the heat that issues from the bottom of the iron, which is the condition to be fulfilled to obtain the efficiencies upon the basis before mentioned. An important advantage gained by using this type of a calorimeter is that the iron operates practically at its normal working temperature and in its natural upright position.

Description of Irons.

Irons No. 1 and 2 are of the same make. The photo No. gives a very good idea of the construction. The heating element consists of two small ribbons wound together spirally, on edge, around a central magnetic core. The ribbon is embedded in an enamel which is a non conductor of electricity. Sheets of mica separate this coil from the bottom surface. The space above the element is packed with some heat insulating compound similar to pulverized asbestos. This top heat insulator is very effective in keeping heat from ascending to the upper parts and rendering them uncomfortable, in fact the handle of this iron never gets more then just warm, and consequently is very comfortable to handle. Altho it might seem that but little heat would be transmitted when the element is on edge this does not prove to be the case. The manufacturers claim for this type is that it has a hot point. In type No. 5 the heating element consists simply of a "zig-zag" piece of high resistance iron about 1/64 inch thick, laid flat wise.

As before, the element is separated from the base by mica. This iron heats up quickly in the middle of the surface and but slowly around the edges. This is best shown by the temperature-time curves on Page 25. The top of this type remains fairly cool but not so much so as in Nos. 1 and 2.

Since the Hysteresis iron requires a coil to heat up the iron core the whole requires a comparatively large space. It is due to this large heating element that causes the top to be at practically the same temperature as the bottom since nearly the whole lower part of the iron forms the magnetic circuit. This high temperature renders this type rather uncomfortable to use yet it operates very efficiently. Of necessity the heat storage capacity is very large and makes it desirable for heavy work.

Construction of Apparatus.

The calorimeter finally deceided upon was constructed as follows: A rectangular copper box 10 inches wide, 12 inches long, and 4 inches deep, covered with a lid containing a recess 6 inches wide by 8 inches long. A copper stirrer with a vertical axle was placed at the middle of one end of the calorimeter. A small pulley placed upon the top of the vertical axle furnished the means for propulsion by a small round belt. The bottom and sides of the box were covered with two thicknesses of abestos paper, the top was covered with a one layer of the paper with the exception of a portion of the bottom of the recess which was left bare. The whole was placed in a wooden box of a cross section enough larger to leave an intervening space of 1/2 inch, on all sides, which was packed with a mineral wool. With the calorimeter thus covered there was found to be a negligible amount of radiation. A 110 volt D.C. fan

motor was supplied with 20 volts from the storage battery, giving a speed of 270 R.P.M. which propelled the stirrer at the proper rate.

Description of Test.

The calorimeter was filled with water at room temperature to within 3/4 inches of the top, this being found sufficient to cause it to rise well up around the recess in the top. The amount of water required when the calorimeter was thus filled was about 13 lb. In each case, however, the water was always carefully weighed. The top was next placed upon the box and the stirrer set in motion so that the contents might become thoroughly mixed and have the same temperature thru-out. After the temperature had become stationary the readings of the four thermometers placed on the four sides of the calorimeter were carefully read and the average of the four taken as correct. (The thermometers had been previously calibrated by comparison with a laboratory standard). The iron was now placed upon the bare space on the recess in the lid, care being taken to have the surfaces as near flat as possible and to have them clean and polished. The time at which the current was turned on, and turned off again at the end of one hour was noted. The reason for running one hour was that the temperature rise during that time did not exceed 65 degrees so there was no loss from vaporization of water. At the end of the hour, readings of temperature were taken, and at frequent intervals until it had reached its maximum value and again receded, for several degrees. When it was desired to obtain data on current consumption, power factor, and wattage, the voltmeter, wattmeter and ammeter were all read simultaneously at intervals of five minutes through out the test. Three different makes were tested in the above manner.

Temperature Tests.

The next tests run were those to obtain the temperature to which the top of the iron came while under operation, since it is important to know what effect the different designs have upon the comfort with which they may be handled and also to see how much heat is wasted by radiation from the top of the unit.

These tests were very simple in their operation. Thermometers were placed upon the top of the iron with their mercury bulbs in close contact with the iron surface. The current was turned on and the temperature rise taken at equal intervals of time until the iron reached its normal working temperature.

The iron was next placed in its normal position and temperatures taken by thermometers at the middle of the bottom, and at the point, readings being taken as before, up to the normal working temperature of the iron. Curves were plotted for both tests and are shown on pages 23, 24 and 25.

Sources of Error in Data.

While it was not found possible to eliminate all the error that might enter into tests of the above nature a great many of them were eliminated to such an extent that their presence does not materially affect the usefullness of the data. In designing a standard piece of apparatus it was intended to make something that was inexpensive yet accurate and simple.

Reference to the cooling curve on page 26 shows that cooling, while the unit was at its maximum temperature, occured at a rate of 0.10 degrees per minute, which is a negligible amount. Curves were plotted on two types of irons and it can be seen that this cooling occurs more rapidly in No. 2 than in No. 3, showing the effect of a

small and large heat capacity.

The purpose of the reinforcing ribs is to give rigidity to the surface on which the iron rests, thus making a flat surface when the weight of the unit is imposed. The need of close contact between the surface of the heating element and the calorimeter is very great since it has been found that a very large amount of heat is lost thru poor contact. This theory is very closely followed out in all electric appliances on the market to-day.

The stirrer is essential, else the water will be unevenly heated-that at the top becoming much hotter that that at the bottom of the calorimeter. It is evident that any such condition as this would render the results worthless. The design of stirrer used was found to keep the water thruout the box at the same temperature, the test for any difference in temperature being made by placing a thermometer at different points around the vessel and at different depths of water.

The insulation placed on the bottom, sides and top of the calorimeter, as described, allowed but very little radiation, really a very small percent since the volume of water was comparatively large.

The purpose of the recess in the lid was to provide a means of bringing the heating surface of the iron in contact with the water near its center of gravity, a condition which could not have been realized in any other convenient way. This also makes it unnecessary to fill the calorimeter to the top with the resultant danger of spilling part of the water. The air space between the sides of the iron and the calorimeter, is about one inch, thus prohibiting any heat from being transferred from the sides of the

iron to the surrounding water. The photograph on Page 22 shows a good general view of the apparatus. Details of construction are shown in the drawing on Page 20.

The total error that is liable to enter into obtaining efficiencies by this calorimetric method will probably never exceed the difference between the percent efficiencies shown for two tests on the same iron. While this difference amounts to as much as one percent it is as close an estimate as we desire on apparatus of this kind. The value of the method if adopted as a standard and applied to all irons, is that it furnishes a close estimate of efficiencies and a fair means of comparison regardless of any characteristics peculiar to a certain type.

Discussion of Results.

The various irons with their corresponding efficiencies, power factors, wattage, and cost of operation, based on a rate of 5 cents per K.W.Hr., are shown in Table 1. Taken as a whole it is seen that the average percent is in the region of 60 which is much better than we might expect. The variance in the results for the different kinds of irons may be ascribed to the design of their heating elements, those having the better distribution showing up the best. All the irons, with the exception of one, are 6 pound, the other is a 7 pound. It is seen by inspection of the table that iron No. 1 operates more efficiently on A.C. The only apparent reason for this is that there is a certain amount of heat developed by iron loss that does not appear when the unit is operated on D.C. The D.C. units develop their heat by simple I^2R loss, while the A.C. iron heats up by virtue of the excessive iron loss. The arrangement of the heating elements is clearly shown by the photographs on pages

The idea prevalent in all the samples is that of a heating element entirely separate from the base but in close enough contact to provide it with the necessary heat. Altho the different irons show practically the same efficienciy, the time consumed in imparting the heat to the water was considerably different. For example, in specimen No. 1 the unit heated up quite rapidly and cooled down at a comparatively rapid rate, the maximum temperature of the water being reached soon after the current was shut off. Iron No. 3 however, heated slowly and continued to rise in temperature for a considerable time after the current was shut off.

The curves showing the temperature rise with time (Page 23), up to the working temperature for different points on the bottom, are quite interesting in that they show which of them is most desirable for the fine work, requiring a hot point, and which for the heavier material, requiring a large heat capacity but needing no part of the iron hotter than any other.

Derivation of Formulae and Sample Calculation of Efficiency.

The definition of a gram calorie is expressed as the amount of heat required to raise one gram of water one degree centigrade, and is equal to 4.16×10^7 ergs. Stated in the form of an equation:

$$1 \text{ gram cal.} = 4.16 \times 10^7 \text{ ergs whence,}$$

$$1 \text{ k.g. cal.} = 4.16 \times 10^{10} \text{ ergs.}$$

The unit of work for electrical calculations is the watt, and is defined as doing work at the rate of 10^7 ergs per second. Expressed as a formula:

$$1 \text{ watt} = 10^7 \text{ ergs per second, whence}$$

$$1 \text{ watt hour} = 10^7 \times 60^2 = 3.6 \times 10^{10} \text{ ergs, and}$$

$$1 \text{ K.W. hour} = 3.6 \times 10^{13} \text{ ergs.}$$

Substituting here the value of 1 k.g. calorie in ergs, we have:

$$1 \text{ K.W. hr.} = \frac{3.6 \times 10^{13}}{4.16 \times 10^{10}} = 865.38 \text{ k.g. calories.}$$

This furnishes us with a convenient unit for converting power, as commonly expressed in K.W. hours, into a heat equivalent.

In making the calorimeter calculations, correction is made for the heat absorbed by the copper. The specific heat of copper is .095. The other data is tabulated as follows:

Weight of copper calorimeter = 1.500 k.g.

Weight of water in calorimeter (see page 14) = 5.52 k.g.

Rise in temperature of water (maximum) = 43.45 degrees C.

Time of run = 1 hour.

Average K.W. input = .449 (average of 5 minute readings).

Heat received by the water = 5.52 x 43.45 = 239.5 calories.

Heat received by copper calorimeter = .095 x 1.5 x 43.45 = 6.20 calories.

Total heat received from iron (i.e. output) = 245.70 calories.

Total input (heat equivalent) = .449 x 1 x 865.38 = 398 "

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{245.70}{389.00} \times 100 = 63.20\%$$

The above method was adopted for all efficiency calculations, it being simple, short and accurate.

Tests of Iron No. 1 on D.C. from Storage Battery.

Time Day	Min.	Volts	Amp.	Watts	Temperature degrees Centigrade
9:49	0	110	4.6	506	18.25
9:50	1	110	4.35		
9:51	2	110	4.25		
9:52	3	110	4.20		
9:54	5	110	4.12	453	
9:56	7	110	4.08		
10:00	11	110	4.04	445	
10:13	24	110	3.98	437	
10:20	31	110	3.98	437	
10:30	41	110	3.98	437	
10:40	51	110	3.95	434	
10:49	60	110	3.95	434	56.75 current off
11:00					58.25 maximum.
11:12					57.25
11:23					56.10

Rise in temperature = 40 degrees Centigrade.

Weight of water in calorimeter = 6.13 kg.

Efficiency = 63.5%.

Test of Iron No. 1 on D.C. from Storage

Battery. Second Test.

Time	Volts	Amp.	Watts	Temperature degrees Centigrade.
9:14	110	4.6	506	17.95
9:14 1/2	110	4.4	484	
9:20	110	4.1	452	
9:30	110	4.0	441	
9:45	110	3.98	438	
9:55	110	3.95	435	
10:14	110	3.95	435	57.45 current off.
10:22				59.30
10:30				59.40 maximum.
10:40				58.10
10:50				57.60
11:00				56.80

Rise in temperature = 41.45 degrees Centigrade.

Weight of water in calorimeter = 5.79 kg.

Efficiency = 64.5%.

Test of Iron No. 2 on A. C.

Time	Volts	Amp.	Watts	Temp.	P.F.
3:00	110	4.4	460	23.9	.95
:05	110	4.02	408		.924
:15	110	3.98	400		.914
:20	110	3.98	396		.905
:25	110	3.92	394		.913
:30	110	3.93	396		.917
:35	110	3.93	395		.914
:40	110	3.93	390		.901
:45	110	3.93	390		.901
:50	110	3.97	395		.904
:55	110	3.97	390		.894
4:00	110	3.93	390	64.65	.903 current off.
4:10				66.20 maximum.	

Rise in temperature = 42.3 degrees Centigrade.

Weight of water in calorimeter = 5.42 kg.

Efficiency = 68%.

Tests of Iron No. 3 on A.C. (Power plant).

Time	Volts	Amps.	Watts	Temperature degrees Centigrade.
2:47	110		520	23.50
:50	110		485	
:55	110		450	
3:00	110		455	
:05	110		455	
:10	110		455	
:15	108.5		440	
:20	108.5		438	
:25	110		439	
:30	110		434	
:40	110		430	
:45	110		430	
:47	110		430	58.3 (current off).
:54				61.7
4:10				64.7 (maximum).

Rise in temperature = 41.2 degrees Centigrade.

Weight of water in calorimeter = 5.56 kg.

Efficiency = 60.4%.

Voltage fluctuated badly through-out this experiment. It was kept constant as far as possible by use of a rheostat, special care being taken to have voltage at 110 when readings were taken.

Test of Iron No. 3 on A. C. (Power plant).

Time	Volts	Watts	Temperature degrees Centigrade.
10:00	110	500	17.8
:05	110	451	
:13	110	445	
:20	110	455	
:25	110	460	
:30	110	448	
:35	110	445	
:40	110	445	
:45	110	443	
:50	110	441	
:55	110	440	
11:00	110	430	55.8 (current off).
:05			58.3
:10			59.6 (maximum).

Rise in temperature 43.45 degrees Centigrade.

Weight of water in calorimeter = 5.52 kg.

Efficiency = 63.2%.

Tests of Iron No. 3 on A.C. (Separate generator).

Time	Volts	Amp.	Watts	P.F.	Temperature degrees Centigrade.
10:05	110	6.85	522	.693	20.20
:10	110	6.17	472	.696	
:15	110	5.99	468	.711	
:20	110	5.97	460	.700	
:25	110	5.77	459	.739	
:30	110	5.68	449	.719	
:35	110	5.59	447	.726	
:40	110	5.53	447	.734	
:45	110	5.53	447	.734	
:50	110	5.53	447	.734	
:55	110	5.47	447	.742	
11:00	110	5.47	447	.742	
:05					56.80 (current off).
:20					62.20
:30					63.75 (maximum).
:45					63.25
12:00					62.30

Rise in temperature = 43.55 degrees Centigrade.

Weight water in calorimeter = 5.72 kg.

Efficiency = 63.60%.

Tests on Iron No. 4. A. C. (Separate Generator).

Time	Volts	Amp.	Watts	P. F.	Temperature degrees Centigrade.
2:00	110	6.55	485	.673	21.70
:05	110	6.94	471	.710	
:10	110	5.91	469	.722	
:15	110	5.84	460	.717	
:20	110	5.69	450	.719	
:25	110	5.62	450	.728	
:30	110	5.53	439	.721	
:35	110	5.44	434	.725	
:40	110	5.40	430	.724	
:45	110	5.40	428	.721	
:50	110	5.40	430	.724	
:55	110	5.34	425	.724	
3:00	110	5.37	427	.723	(current off).
:15					63.20
:26					63.60 (maximum).

Rise in temperature = 41.90 degrees Centigrade.

Weight of water in calorimeter = 5.61 kg.

Efficieny = 62.80%.

Test of Iron No. 5 on A. C. (Separate Generator).

(7 pound iron)

Time	Volts	Amp.	Watts	P. F.	Temperature degrees Centigrade.	
5:00	110	5.97	650	.990	28.40	
:05	110	5.67	595	.954		
:10	110	5.47	575	.956		
:15	110					
:20	110	5.35	567	.964		
:25	110	5.30	560	.960		
;30	110	5.30	560	.960		
:35	110	5.28	555	.955		
:40	110	5.27	558	.964		
:45	110	5.25	560	.970		
:50	110	5.25	555	.963		
:55	110	5.25	560	.970		
6:00	110	5.22	560	.975	74.10	(current off).
:05					75.30	
:10					76.70	
:15					77.10	(maximum).
:20					77.06	
:30					76.40	

Rise in temperature = 48.70 degrees Centigrade.

Weight water in calorimeter = 5.54 kg.

Efficiency = 56.10%.

The results of the tests made with the calorimeter upon the electric flat irons is shown in the following table:

Table No. 1.

Iron No.	Current Used.	Av. Power Factor	Av. Watts for 1st. Hour.	Watts at end of 1st. hr.	Mfgrs. (Watts) rating.	Operation perhr.	Efficiency per cent.
1	D. C.		446	435	418	2.23	63.5
1	D. C.		441	435	418	2.21	64.5
2	A. C.	.911	400	390	418	2.00	68.0
3	A. C.		450	430	450	2.25	60.4*
3	A. C.		449	430	450	2.25	63.2
3	A. C.	.724	458	447	450	2.29	63.6
4	A. C.	.718	446	427	450	2.23	62.8
5	A. C.	.964	572	560	550	2.86	56.1

No. 1 and 2 are the same make and are designed for either A. C. or D. C. No. 3 is the Hysteresis type, also No. 4. No. 5 is designed for either A. C. or D. C., and is a 7 lb. iron.

* Voltage fluctuated badly.

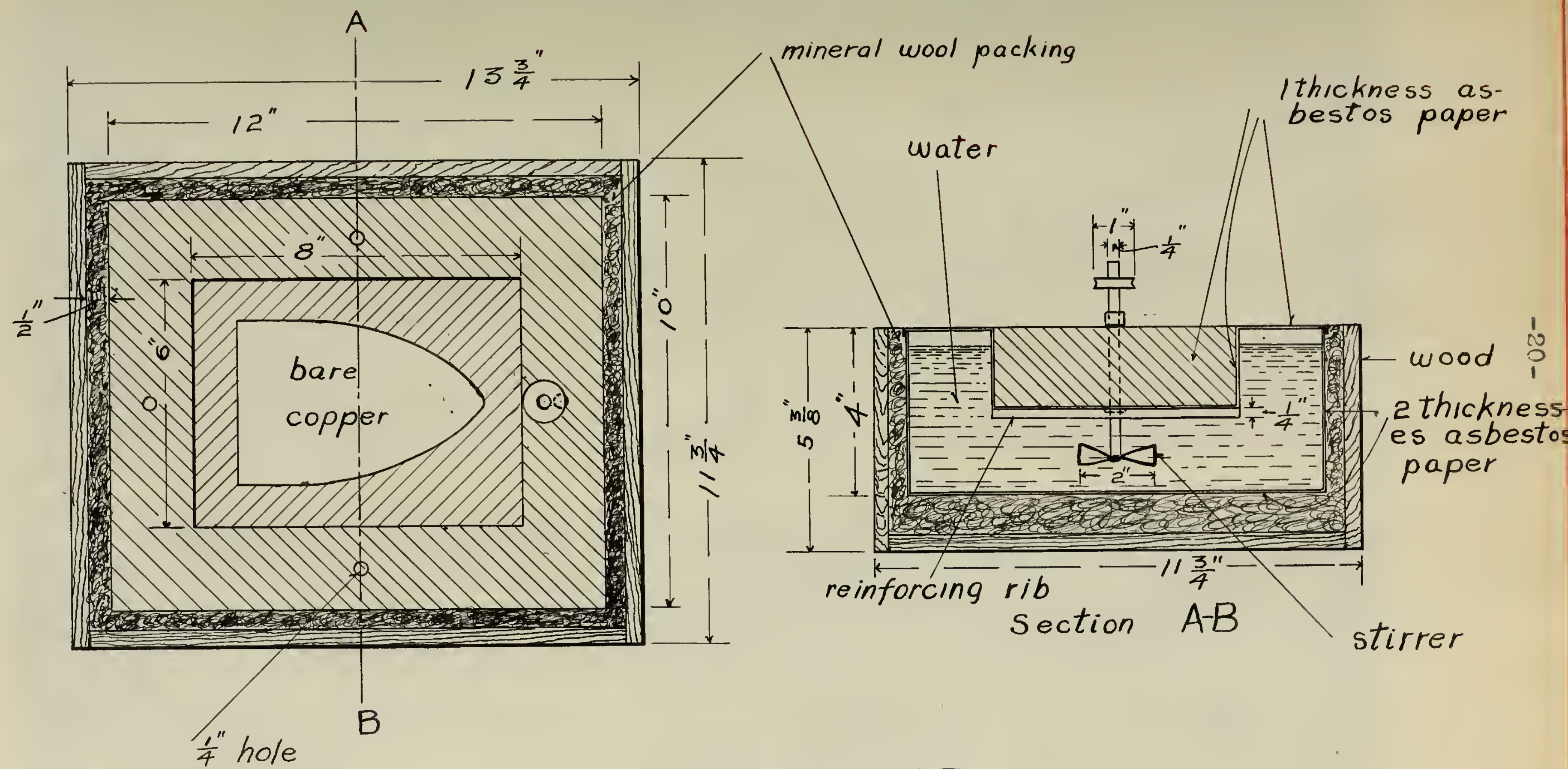
Cost of power for operation is given in cents per hour, and based on a rate of 5 cents per K. W. Hr.

C O N C L U S I O N .

The comparatively small amount of power consumed by the electric flat iron, and the ability to obtain this power at a low rate from the Central Station gives a very decided stimulus to the introduction of irons on the market. This is but the fulfillment of the demand of the Central Station manager, for it was doubtless due to his need of appliances to increase the day load, that the iron, in all probability, was put on the market.

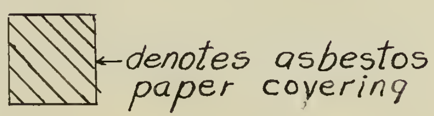
A quite interesting feature is in the effect that the iron with a power of .7 would have upon the regulation of the generator. In a fairly large town we easily have an iron load of several hundred K.W. on one or two days of the week. Fortunately, however this "iron" load comes in the day time when there are not so many lights on and the regulation is not so important.

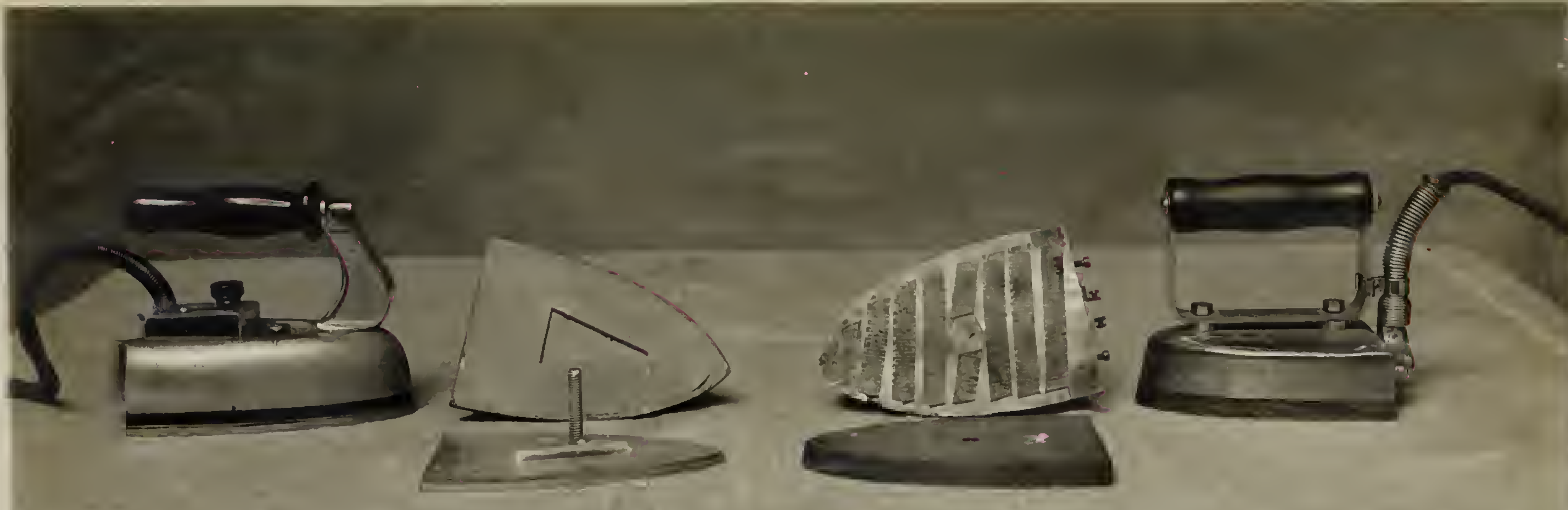
Any attempt to increase the use of electricity is a step in advance toward the development of the electrical industry, and these should be welcomed and encouraged whenever possible. It is safe to say that we have just begun to realize the many uses to which electric power may be applied successfully and economically. Already the number of electrically heated appliances has become so great that any attempt to make a complete test of all would be well near impossible, the results shown in this thesis, however, may be taken as representative of all, to a large extent. It is hoped that the data herein tabulated may be useful in bringing the electrical appliances to a higher state of perfection.



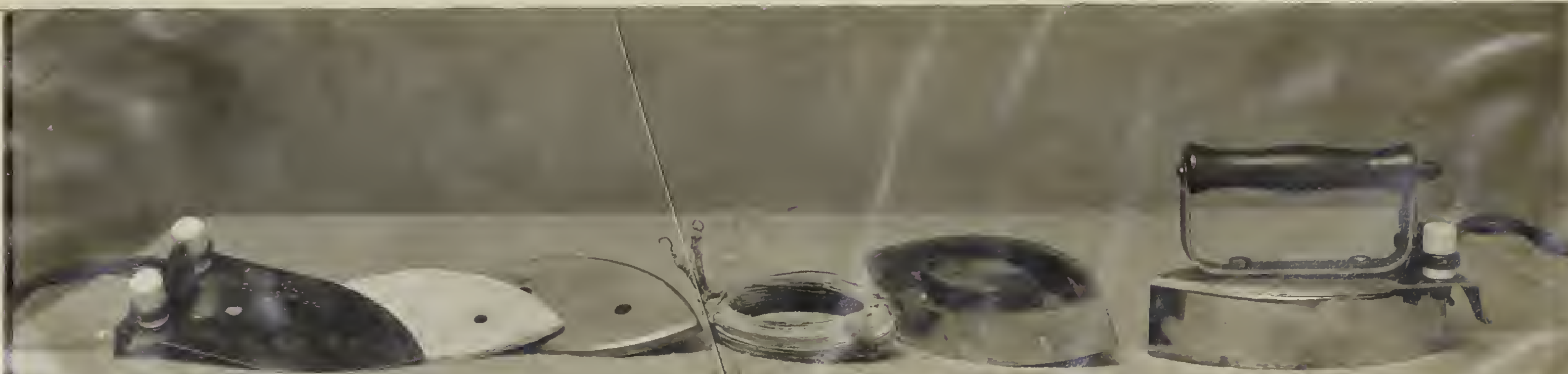
CALORIMETER

Scale: $\frac{1}{4}'' = 1''$





No. 1. Heating element and base of No. 1. Heating element and base of No. 5. No. 5.



a. b c. d. e.

Iron No. 3 and its component parts. a = top shield, b = asbestos insulator, c = iron plate composing part of magnetic circuit, d = coil of No. 18 asbestos covered copper wire, e = shell of iron, completing magnetic circuit and ironing surface. Space between coil and shell packed with mineral wool.

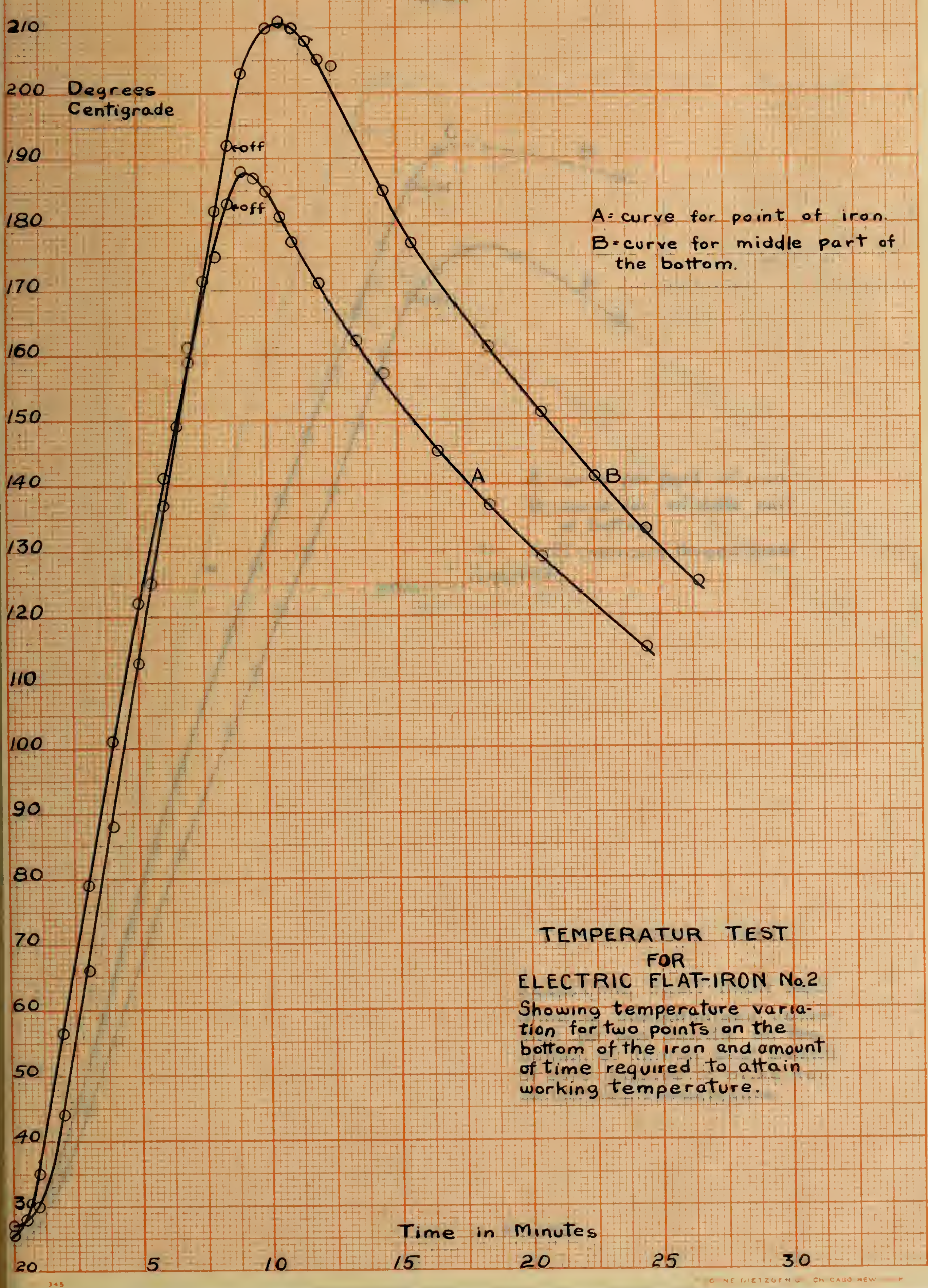
Calorimeter

a = arrangement of calorimeter in surrounding box. "b" shows the lid inverted, giving a view of reinforcing ribs and stirrer.

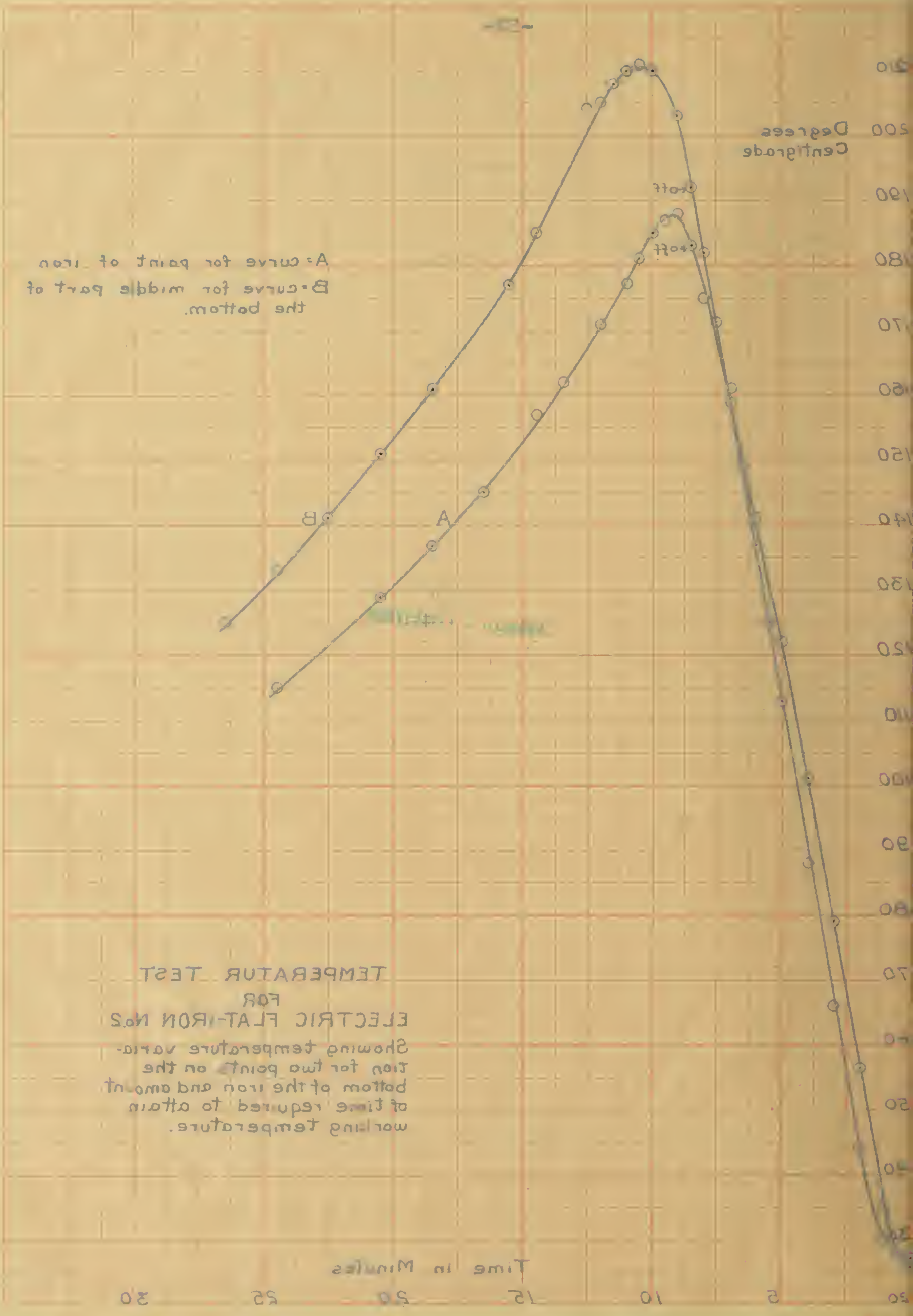
Key to numbering irons.

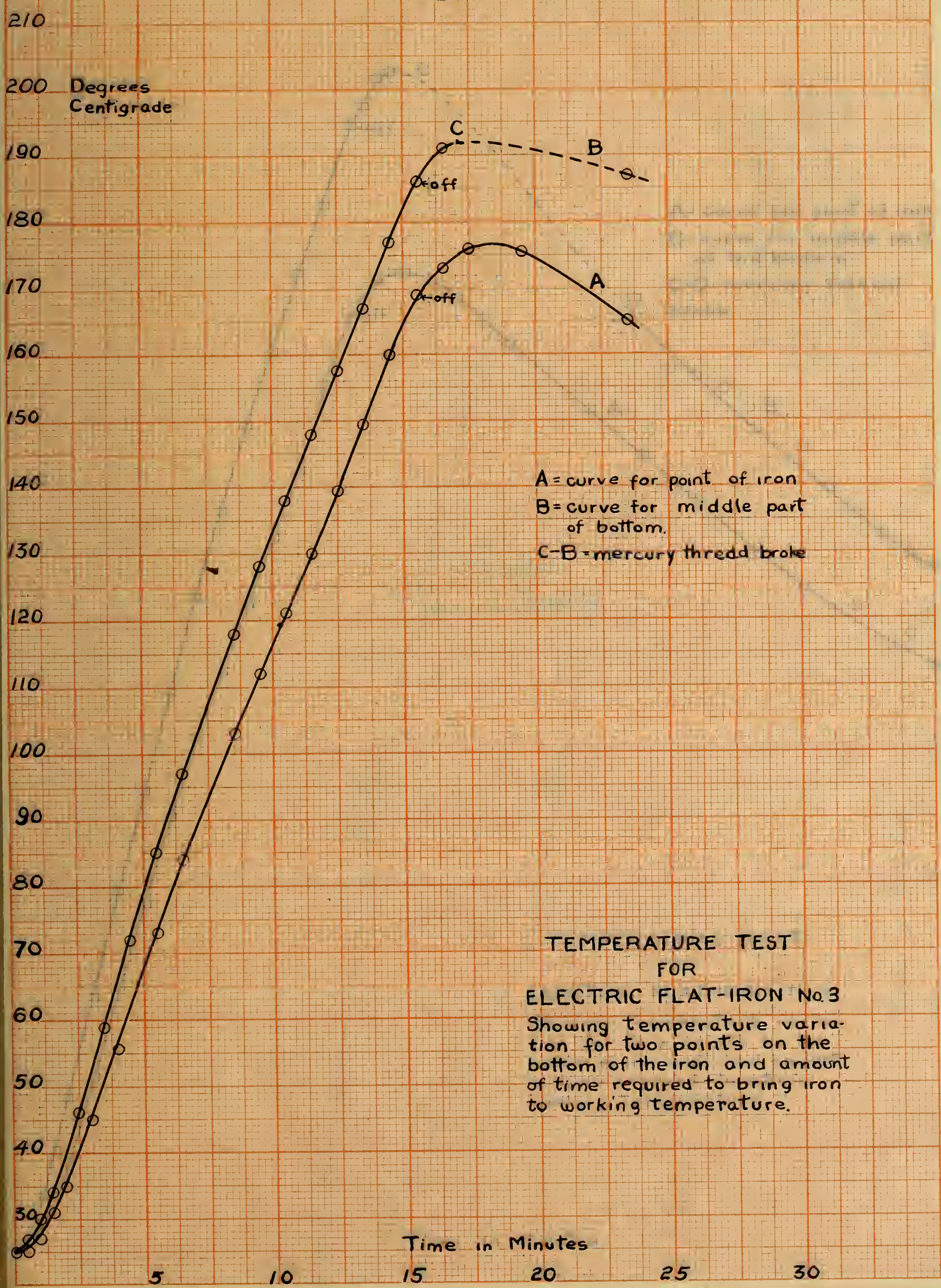
No. 1 = Universal iron	)	2 irons.
No. 2 = Universal iron	)	
No. 3 = Watson iron	)	2 irons.
No. 4 = Watson iron	)	

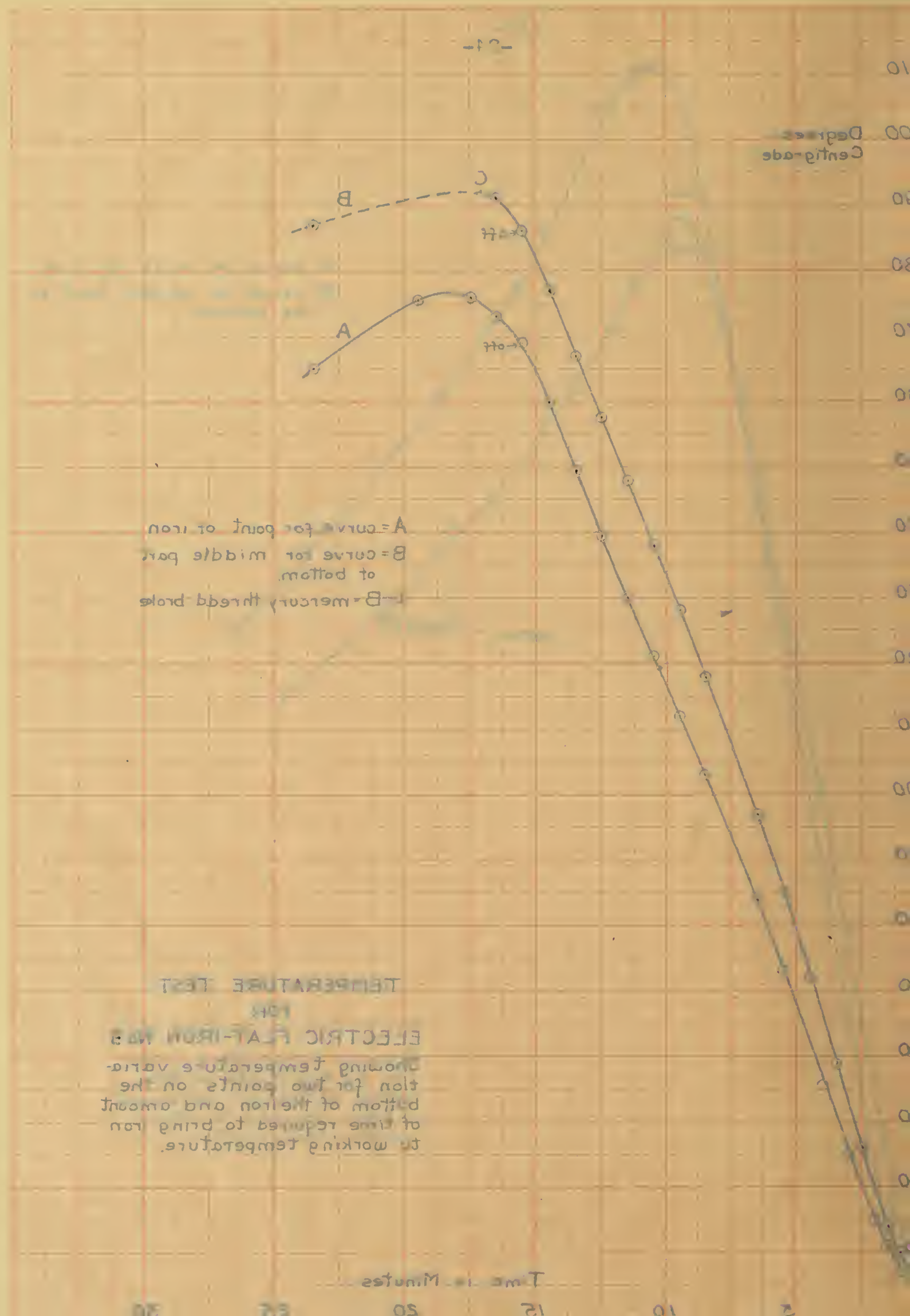
No. 5 = Westinghouse iron.



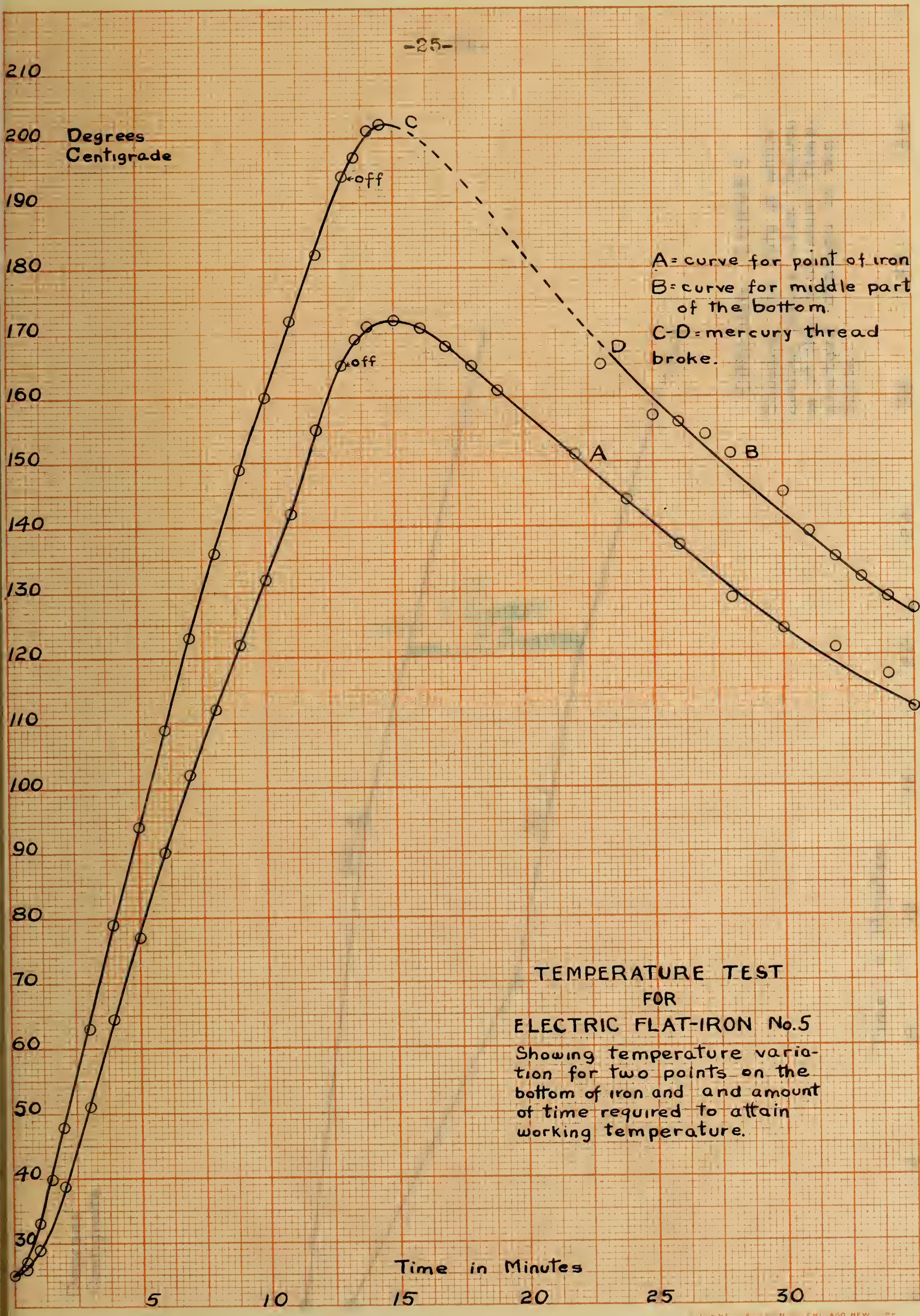
210
200
Degrees Centigrade
190
off
180
off
A = curve for point of iron.
B = curve for middle part of the bottom.
170
160
150
140
A
B
130
120
110
100
90
80
70
TEMPERATUR TEST FOR ELECTRIC FLAT-IRON No. 2
Showing temperature variation for two points on the bottom of the iron and amount of time required to attain working temperature.
60
50
40
30
20
Time in Minutes
5
10
15
20
25
30


Degrees
Centigrade
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
50
A: curve for point of iron
B: curve for middle part of the bottom.
off
off
A
B
TEMPERATUR TEST
FOR
ELECTRIC FLAT-IRON No.2
Showing temperature variation for two points on the bottom of the iron and amount of time required to attain working temperature.
Time in Minutes
30
25
20
15
10
5

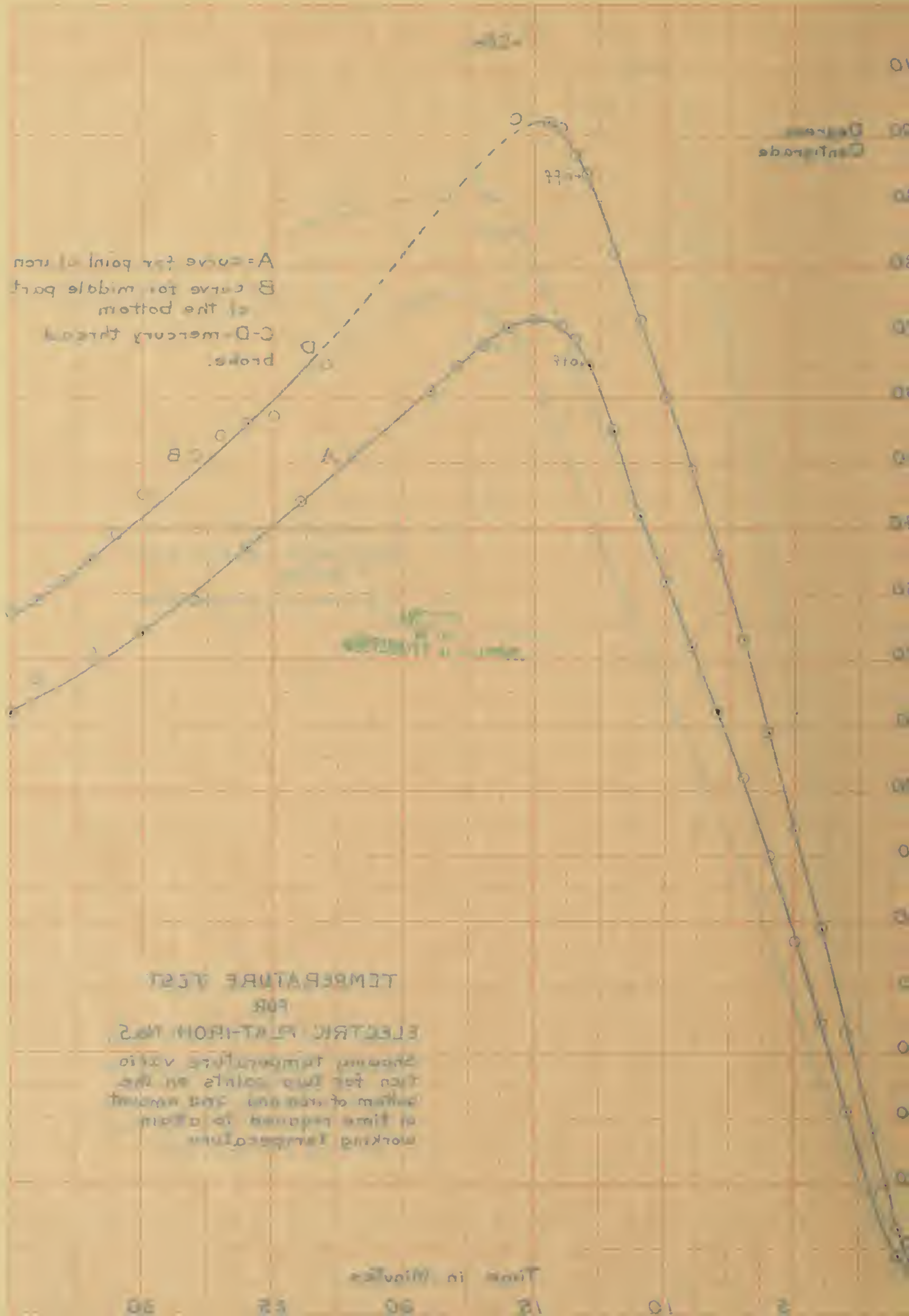

Degrees Centigrade
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
C
B
A
off
off
A = curve for point of iron
B = curve for middle part of bottom.
C-B = mercury thread broke
TEMPERATURE TEST FOR ELECTRIC FLAT-IRON No. 3
Showing temperature variation for two points on the bottom of the iron and amount of time required to bring iron to working temperature.
Time in Minutes
5
10
15
20
25
30

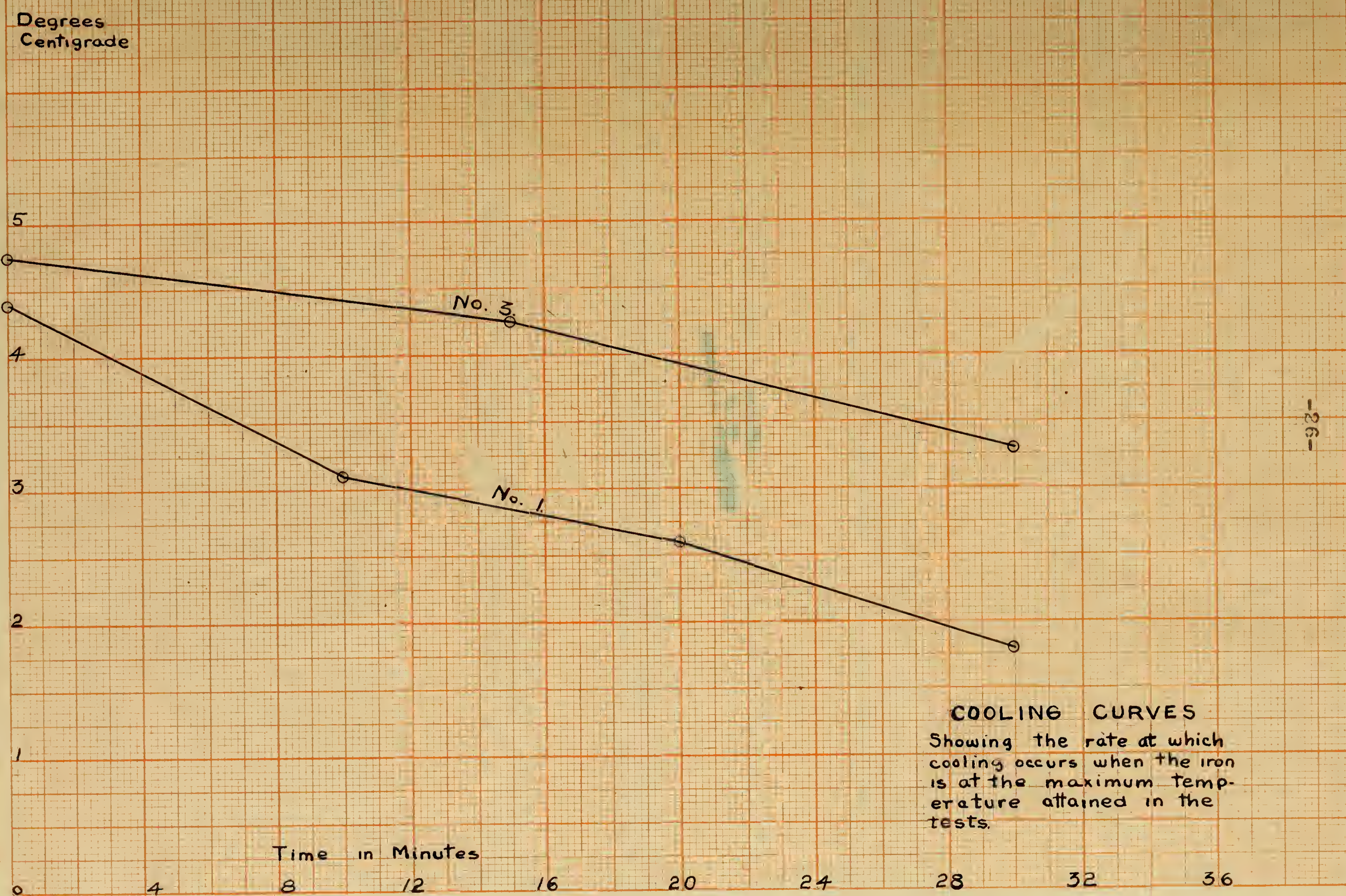


Degrees Centigrade
B
C
A
A=curve for point of iron
B=curve for middle part of bottom
L-B=mercury thread broke
TEMPERATURE TEST
FOR
ELECTRIC FLAT-IRON No. 3
Showing temperature variation for two points on the bottom of the iron and amount of time required to bring iron to working temperature.
Time in Minutes



210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
Degrees
Centigrade
C
off
off
D
A
B
A= curve for point of iron
B= curve for middle part of the bottom.
C-D= mercury thread broke.
TEMPERATURE TEST
FOR
ELECTRIC FLAT-IRON No.5
Showing temperature variation for two points on the bottom of iron and and amount of time required to attain working temperature.
Time in Minutes
5
10
15
20
25
30


Degrees Centigrade
A=curve for point of iron
B curve for middle part of the bottom
C-D-mercury thread broke.
TEMPERATURE TEST
FOR
ELECTRIC FLAT-IRON No.5.
Showing temperature variation for two points on the bottom of iron and amount of time required to attain working temperature
Time in Minutes
30
25
20
15
10
5



COOLING CURVES

Showing the rate at which cooling occurs when the iron is at the maximum temperature attained in the tests.